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Optimal Placement of UPFC for Voltage Drop Compensation

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(Abstract) This paper proposes an approach to find the optimal placement of Unified Power Flow Controller (UPFC) based on the sensitivity of voltage drop with respect to increase the network loads. In order to reduce the solution space, we will establish a priority list. UPFC allows concurrent control of active and reactive power flow and voltage amplitude at the UPFC terminals. These specifications give UPFC the ability to improve the efficiency of the power system during various operating situations. For the case studies, IEEE 14-bus test system is selected and a UPFC is placed in the system. Simulation results show that the proposed method is able to detection the optimal placement of UPFC. Also simulation results show that with the installation of UPFC in network, voltage drop due to increasing the load is compensated.

Keywords: FACTS devices; UPFC; Voltage Drop; Increase the Network Load; Compensation.

1. INTRODUCTION

Voltage drop compensation is a significant issue in electrical power systems. Since the voltage drop can be compensated by controlling the reactive power, shunt and shunt-series Flexible AC Transmission Systems (FACTS) devices play a great role in controlling the reactive power flow to the power systems. Also FACTS devices can decrease power losses, improve voltage profiles, control transmission power flow and control power demanded from the power networks. The main problem about the FACTS devices is high cost of installing these devices. Therefore, the best placement of installation these devices should be well determined.

Many papers have been presented on the optimal placement of FACTS devices in order to voltage drop compensation. In [1], PSO (Particle Swarm Optimization) technique has been proposed for determining the optimal placement of SVC (Static Var Compensator) in order to voltage stability enhancement under contingency condition. In [2], HSA (Harmony Search Algorithm) and GA (genetic algorithm) are used for optimal placement of FACTS devices considering voltage stability and losses. In [3], the objective functions include congestion management and improve voltage stability. In [4], the placement of FACTS devices in order to enhance voltage based on PSO technique. In [5] and [6], placement of FACTS devices has been done for voltage profile improvement.

The objective of this paper is proposing an approach to find the optimal placement of shunt and shunt-series FACTS devices (such as UPFC, SVC and …) based on the sensitivity of voltage drop with respect to increase the network loads. In this paper, optimal placement of UPFC has been studied.

The rest of the paper is organized as follows: static model and performance of UPFC is described in section 2. The proposed placement methodology for UPFC is presented in Section 3. Simulation results along with some observations are discussed in Section 4. In this section IEEE 14-bus test system is used for the case studies. The paper ends with a summary conclusion in the final section.

2. STATIC MODEL OF UPFC

The Unified Power Flow Controller is the perfect device among the FACTS devices. The structure of UPFC that shown in Fig. 1, consisting of two "back to back" AC to DC voltage source converters (VSC) operated from a common DC link capacitor. First converter (converter 1 or shunt converter) is connected in shunt and the second converter (converter 2 or series converter) in series with the transmission line [7], [8].

The shunt converter is mainly used to supply active power demand of the series converter via a common DC link. Converter 1 can also generate or absorb reactive power, if it is desired, and thereby provide independent shunt reactive compensation for the line.

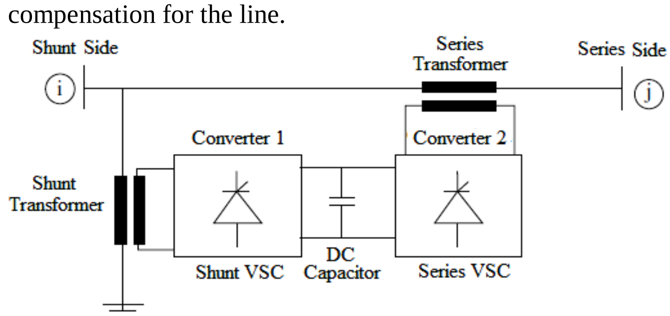

Figure 1. Structure of UPFC.

Converter 2 provides the basic function of the UPFC by injecting a voltage with controllable amplitude and phase angle in series with the line via a voltage source, Fig. 2.

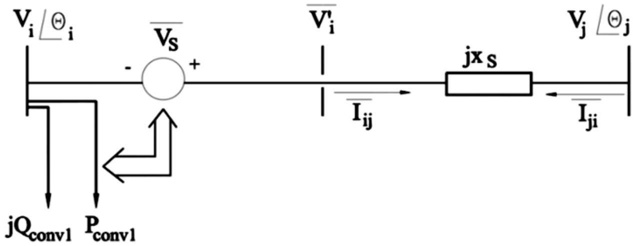

Figure 2. The UPFC electric circuit [8].

The reactance $\mathbf{x_s}$ describes a reactance seen from terminals of the series transformer and is equal to (in p.u. base on system voltage and base power) [7], [8]:

$$x_s = x_k r_{max}^2 \left(\frac{S_B}{S_S}\right) \tag{1}$$

$$b_s = -\frac{1}{x_s} \tag{2}$$

That

$\mathbf{x_k}$: The series transformer reactance.
$\mathbf{r_{max}}$: The maximum value of injected voltage amplitude (p.u.).
$\mathbf{S_B}$: The system base power.
$\mathbf{S_S = S_{conv2}}$: The nominal rating power of the series converter.
Voltage source connected in series is modeled with an ideal series voltage ($\overline{V_s}$) the amplitude and phase is controlled [7], [8].

$$\overline{V_s} = r\overline{V_i}e^{j\gamma}$$
$$0 \le r \le r_{max}^2 \tag{3}$$
$$0 \le \gamma \le 2\pi$$

That

r: The value of injected voltage amplitude (p.u.).
γ: The value of injected voltage angle.

The equations of the UPFC injection model (Fig. 3) are given as [7], [8]:

$$P_{si} = -rb_s V_i V_j \sin(\theta_i - \theta_j + \gamma) \tag{4}$$
$$Q_{si} = -rb_s V_i^2 \cos(\gamma) + Q_{conv\,1} \tag{5}$$
$$P_{sj} = rb_s V_i V_j \sin(\theta_i - \theta_j + \gamma) \tag{6}$$
$$Q_{sj} = rb_s V_i V_j \cos(\theta_i - \theta_j + \gamma) \tag{7}$$
$$P_{i1} = -rb_s V_i V_j \sin(\theta_i - \theta_j + \gamma) - b_s V_i V_j \sin(\theta_i - \theta_j) \tag{8}$$
$$Q_{i1} = -rb_s V_i^2 \cos(\gamma) + Q_{conv\,1} - b_s V_i^2 + b_s V_i V_j \cos(\theta_i - \theta_j) \tag{9}$$
$$P_{j2} = rb_s V_i V_j \sin(\theta_i - \theta_j + \gamma) + b_s V_i V_j \sin(\theta_i - \theta_j) \tag{10}$$
$$Q_{j2} = rb_s V_i V_j \cos(\theta_i - \theta_j + \gamma) - b_s V_j^2 + b_s V_i V_j \cos(\theta_i - \theta_j) \tag{11}$$

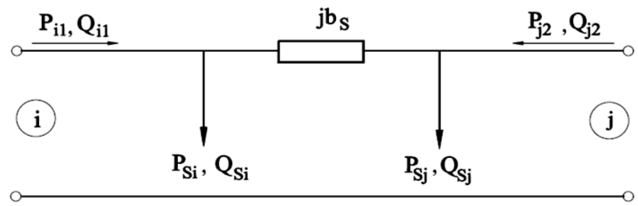

Figure 3. Injection model of the UPFC [8].

To voltage drop compensation, we use the Regulation Voltage mode of UPFC. In this mode that shown in Fig. 4, ($\overline{V_s}$) is injected so that only change the voltage amplitude of buses [8].

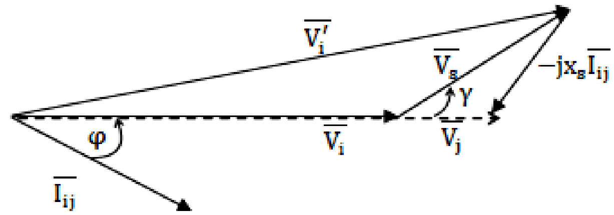

Figure 4. Regulation voltage mode of the UPFC [8].

3. PLACEMENT OF UPFC

In this paper to determine the optimal placement of UPFC, three indices have been proposed.

3.1 Voltage Drop Index (VDI)

This index represents the value of voltage drop in any buses.

$$VDI_{i,j} = \frac{|V_{i,j} - V_{i,j-1}|}{V_{i,j-1}} \tag{12}$$

for $\quad i = 1, \dots, n \quad$ and $\quad j = 1, \dots, m$

That

n : Number of buses connected to load (without generator)
m: Number of steps to increase the network load.
$\mathbf{V_{i,j}}$: Voltage amplitude of $\mathbf{i^{th}}$ bus in the $\mathbf{j^{th}}$ stage of the increased network load ($\mathbf{V_{i,0}}$: Voltage amplitude of $\mathbf{i^{th}}$ bus in the base case).

3.2 Total Voltage Drop Index (TVDI)

This index represents the total voltage drop for any buses at all the stages change the network load. This index is used for ranking the buses.

$$TVDI_i = \sum_{j=1}^{m} VDI_{i,j} \tag{13}$$

for $\quad i = 1, \dots, n \quad$ and $\quad j = 1, \dots, m$

3.3 Total Voltage Drop of Network Index (TVDNI)

This index represents the total voltage drop at the first stage increase the network load. Also this index is used to select the

optimal placement of UPFC and will be calculated only for candidate buses.

$$\mathrm{TVDNI} = \sum_{i=1}^{n} \mathrm{VDI}_{i,1} \qquad (14)$$

for $\quad i = 1, \dots, n$

The proposed algorithm is shown in Fig. 5.

The following criteria have been used for optimal placement of UPFC.

- The lines having transformers have not been considered for the UPFC placement.
- The buses having generator have not been considered for the UPFC placement.

In this article we consider a uniform load growth in all network buses, with k%.

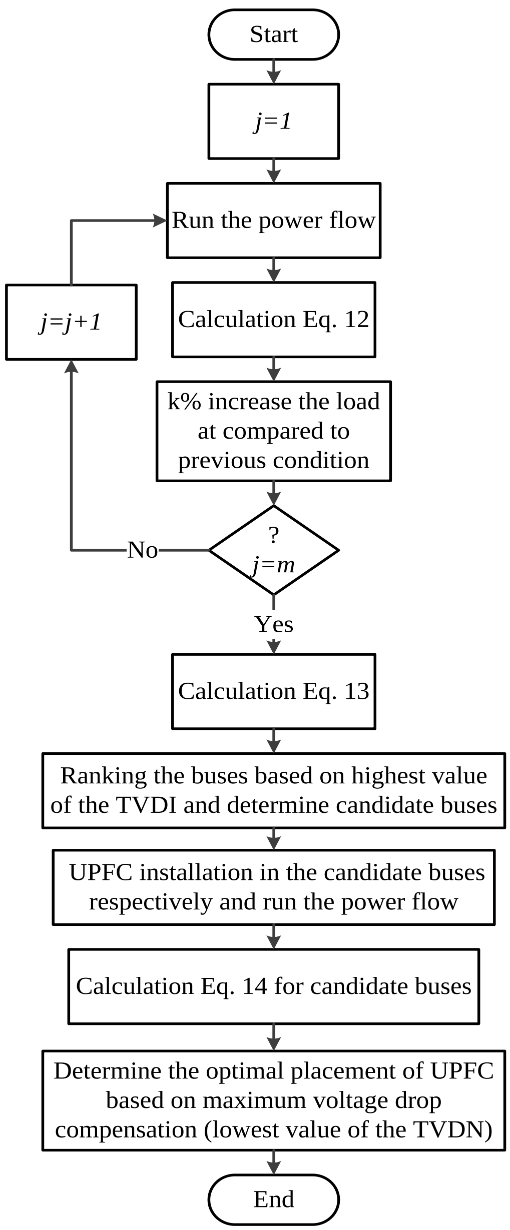

Figure 5. Flow chart of the proposed algorithm.

4. CASE STUDY

The proposed sensitivity approach for optimal placement of UPFC has been tested on IEEE 14-bus system. The system data is found in [9]. It consists of five synchronous machines, three of which are synchronous compensators used only for reactive power support. There are 11 loads in the system totaling 259 MW and 81.3 Mvar. IEEE 14-bus system will be modeled and simulated by using NEPLAN software [10]. In this article m=3 and k=10 have been selected.

Table 1 shows the power flow result before increase the network load.

Table 1. Power Flow Result Before Increase the Network Load

Bus number	**Voltage amplitude (%) Base case ($V_{i,0}$)**
1	106
2	104.5
3	101
4	101.16
5	101.58
6	107
7	104.78
8	109
9	103.17
10	103.09
11	104.66
12	105.33
13	104.68
14	102

Table 2, 3 and 4 shows the results of calculation of VDI for j=1, j=2 and j=3 respectively.

Table 2. Voltage Drop Index for J=1

Bus number	**(j=1)**	
	Voltage amplitude (%)	**$VDI_{i,1}$**(%)
4	100.4	0.75
5	100.83	0.738
7	103.63	1.09
9	101.83	1.3
10	101.69	1.36
11	103.33	1.242
12	104	1.262
13	103.33	1.29
14	100.63	1.343

Table 3. Voltage Drop Index for J=2

Bus number	**(j=2)**	
	Voltage amplitude (%)	**$VDI_{i,2}$ (%)**
4	98.14	2.25
5	98.81	2
7	100.83	2.7
9	98.74	3.03

10	98.52	3.12
11	100.24	2.99
12	100.88	3
13	100.16	3.068
14	97.35	3.26

Table 4. Voltage Drop Index for J=3

Bus number	(j=3)	
	Voltage amplitude (%)	$VDI_{i,3}$ (%)
4	95.57	2.62
5	96.51	2.33
7	97.82	2.985
9	95.52	3.26
10	95.19	3.38
11	96.98	3.25
12	97.62	3.23
13	96.89	3.264
14	94.31	3.12

The $TVDI_i$, as derived in equations (13), have been obtained and given in Table 5. The top 4 ranks, in their order, have been given in column 3 based on Total Voltage Drop Index which are given in 2th column.

Table 5. Rank Orders based on TVDI

Bus number	$TVDI_i$ (%)	Priority number
4	5.62	-----
5	5.038	-----
7	6.775	-----
9	7.59	4
10	7.86	1
11	7.392	-----
12	7.492	-----
13	7.622	3
14	7.723	2

According to the Table 5, buses 10 (line 10-9), 14 (line 14-9), 13 (line 13-14) and 9 (line9-10) are chosen for installing shunt transformer of UPFC respectively. Table 6 to Table 9 shows power flow results (for j=1) after UPFC installation at candidate buses

Table 6. Power flow result with UPFC installed at bus 10

Bus number	(j=1)	
	Voltage amplitude (%)	$VDI_{i,1}$ (%)
4	100.74	0.415
5	101.16	0.413
7	104.45	0.315
9	102.91	0.252
10	103.09	0
11	104.45	0.2
12	104.84	0.465
13	104.19	0.468
14	101.64	0.353

Table 7. Power flow result with UPFC installed at bus 14

Bus number	(j=1)	
	Voltage amplitude (%)	$VDI_{i,1}$ (%)
4	100.65	0.5
5	101.08	0.49
7	104.19	0.56
9	102.56	0.59
10	102.41	0.66
11	104.03	0.6
12	104.77	0.53
13	104.17	0.487
14	102	0

Table 8. Power flow result with UPFC installed at bus 13

Bus number	(j=1)	
	Voltage amplitude (%)	$VDI_{i,1}$ (%)
4	100.68	0.475
5	101.13	0.443
7	104.16	0.59
9	102.49	0.66
10	102.42	0.65
11	104.2	0.382
12	105.2	0.123
13	104.68	0
14	101.61	0.382

Table 9. Power flow result with UPFC installed at bus 9

Bus number	(j=1)	
	Voltage amplitude (%)	$VDI_{i,1}$ (%)
4	100.8	0.36
5	101.2	0.375
7	104.64	0.314
9	103.17	0
10	102.95	0.136
11	104.39	0.258
12	104.88	0.427
13	104.25	0.41
14	101.81	0.186

Table 10 shows the results of calculation of TVDNI for the candidate buses. For an IEEE 14-bus system, according to the Table 10 the optimal placement of UPFC is found as bus 9. Shunt transformer to the bus 9 and series transformer to the line 9-10 has been installed.

Table 10. TVDNI for Some of Candidate Buses

Bus number to installation of UPFC Shunt- Series	TVDNI (%)
10-9	2.881
9-10	2.466
13-14	3.705
14-9	4.417

Power flow results for UPFC Installed at bus 9 (line 9-10) are given in Table 11. Where we can see that installation at bus 9 (line 9-10) would yield a more satisfying result which has improved the voltage amplitude compared to condition before the installation of UPFC

5. CONCLUSION

The present paper focuses on demonstrating a technique for optimal location of UPFC to voltage drop compensation. Voltage drop, Total Voltage Drop and Total Voltage Drop of Network indices are proposed for locating UPFC. The proposed method is tested on IEEE 14-bus system. The results show the capability of the suggested algorithm to optimal placement of UPFC. Benefits of the proposed method are easily for use, runs on any network and use for different types of FACTS devices.

REFERENCES

[1] S. Sakthivel, D. Mary, R. Vetrivel, and V. S. Kannan, "Optimal Location of SVC for Voltage Stability Enhancement under Contingency Condition through PSO Algorithm," International Journal of Computer Applications, Vol. 20, No. 1, pp. 30-36, 2011.

[2] A. Parizad, A. Khazali, and M. Kalantar, "Application of HSA and GA in optimal placement of FACTS devices considering voltage stability and losses," International Conference on Electric Power and Energy Conversion Systems, UAE, pp. 1-7, 2009.

[3] R.S. Wibowo, N. Yorino, Y. Zoka, Y. Sasaki, and M. Eghbal, "Optimal location and control of FACTS devices for relieving congestion and ensuring voltage stability," TENCON, Japan, pp. 539-544, 2010.

[4] R. Benabid, M. Boudour and M. A. Abido, "Optimal placement of FACTS devices for multi-objective voltage stability problem," Power Systems Conference & Exhibition, USA, pp. 1-11, 2009.

[5] Y. Wakabayashi, and A. Yokoyama, "Assessment of Optimal Location of Unified Power Flow Controller Considering Steady-State Voltage Stability," The International Conference on Electrical Engineering, China, pp. 1-6, 2009.

[6] I. Musirin, N. D. M. Radzi, M. M. Othman, M. K. Idris, and T. K. A. Rahman, "Voltage Profile Improvement Using Unified Power Flow Controller via Artificial Immune System," The WSEAS TRANSACTIONS on POWER SYSTEMS, pp. 194-204, 2008.

[7] N. Dizdarevic, "Unified Power Flow Controller in alleviation of voltage stability problem," Ph.D. thesis, University of Zagreb, Faculty of Electrical Engineering and Computing, Dept. Power Systems, October 2001.

[8] S. Izadpanah Tous, and M. Gorji, "Unified Power Flow Controller and its working modes," Presented at the 2011 World Congress on Engineering and Technology, China, 2011.

[9] Power Systems Test Case Archive: 'IEEE 14 Bus Power Flow Test Case', University of Washington, 2003. Available at: www.ee.washington.edu/research/pstca/pf14/pg_tca14bus.htm.

[10] Power system analysis tool for applications in transmission, distribution, generation, industrial, wind power, gas, water and heating. Available at: www.neplan.ch.

Table 11. Power Flow Results for UPFC Installed at Bus 9 (Line9-10)

Bus number	Voltage amplitude (p.u.) Base case ($V_{i,0}$)	Voltage amplitude (p.u.) j=1		Voltage amplitude (p.u.) j=2		Voltage amplitude (p.u.) j=3	
		With UPFC	Without UPFC	With UPFC	Without UPFC	With UPFC	Without UPFC
4	1.0116	1.008	1.004	0.9993	0.9814	0.9871	0.9557
5	1.0158	1.012	1.0083	1.0037	0.9881	0.9926	0.9651
7	1.0478	1.0464	1.0363	1.0432	1.0083	1.0387	0.9782
9	1.0317	1.0317	1.0183	1.0317	0.9874	1.0317	0.9552
10	1.0309	1.0295	1.0169	1.0273	0.9852	1.0248	0.9519
11	1.0466	1.0439	1.0333	1.0384	1.0024	1.0325	0.9698
12	1.0533	1.0488	1.04	1.0399	1.0088	1.0307	0.9762
13	1.0468	1.0425	1.0333	1.0339	1.0016	1.0254	0.9689
14	1.02	1.0181	1.0063	1.0134	0.9735	1.0121	0.9431
TVDNI (%) With UPFC		2.466		4.867		5.403	
TVDNI (%) Without UPFC		10.375		25.418		27.439	

Author Introduction

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